Switching Concerns for Generators

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Transmission Planning

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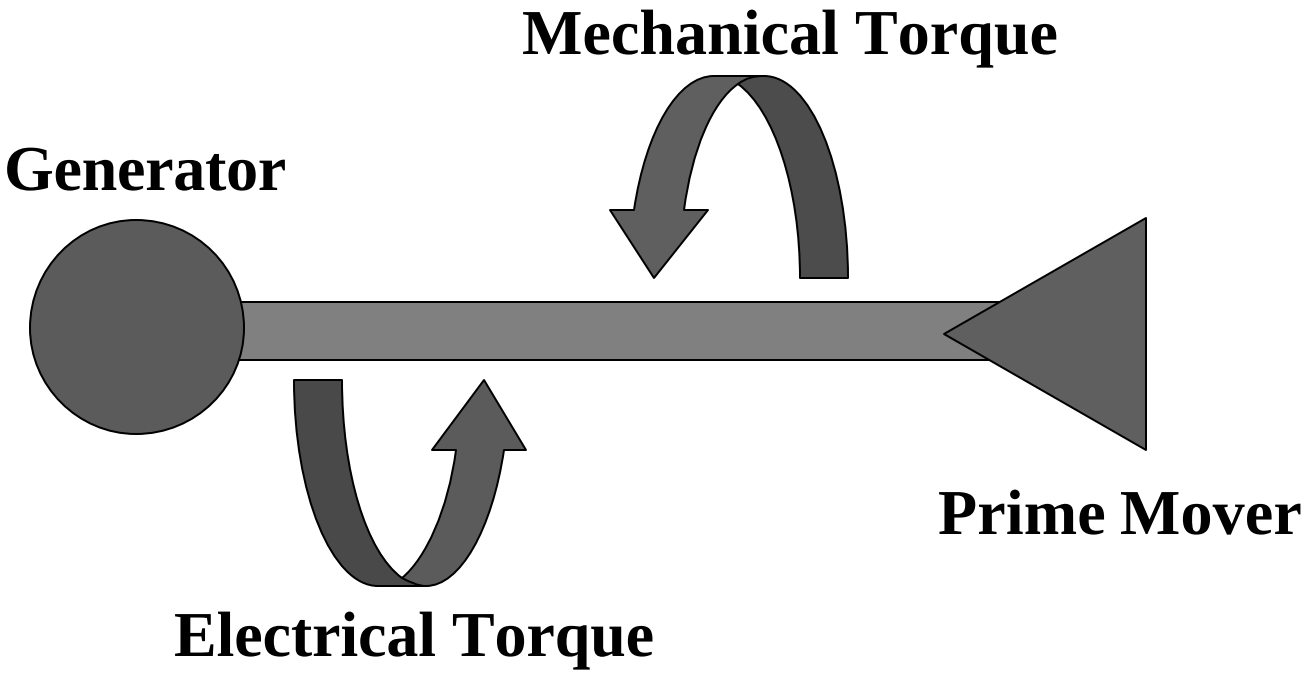
Turbine-Generator System



During steady-state conditions, the electrical torque created by the generator is equal and opposite to the mechanical torque created by the prime mover. The net torque equals zero.

Swing Equation

Swing Equation

$$J*a = T_{mech} - T_{elec}$$

Where: J = Moment of Inertia

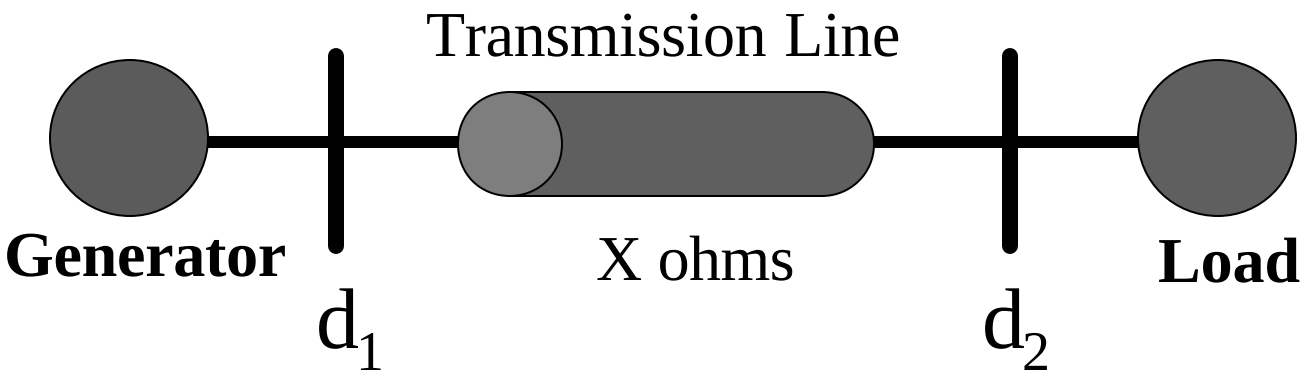
a = Machine Acceleration

During steady-state, $T_{elec} = T_{mech}$.

Therefore, the acceleration a is zero.

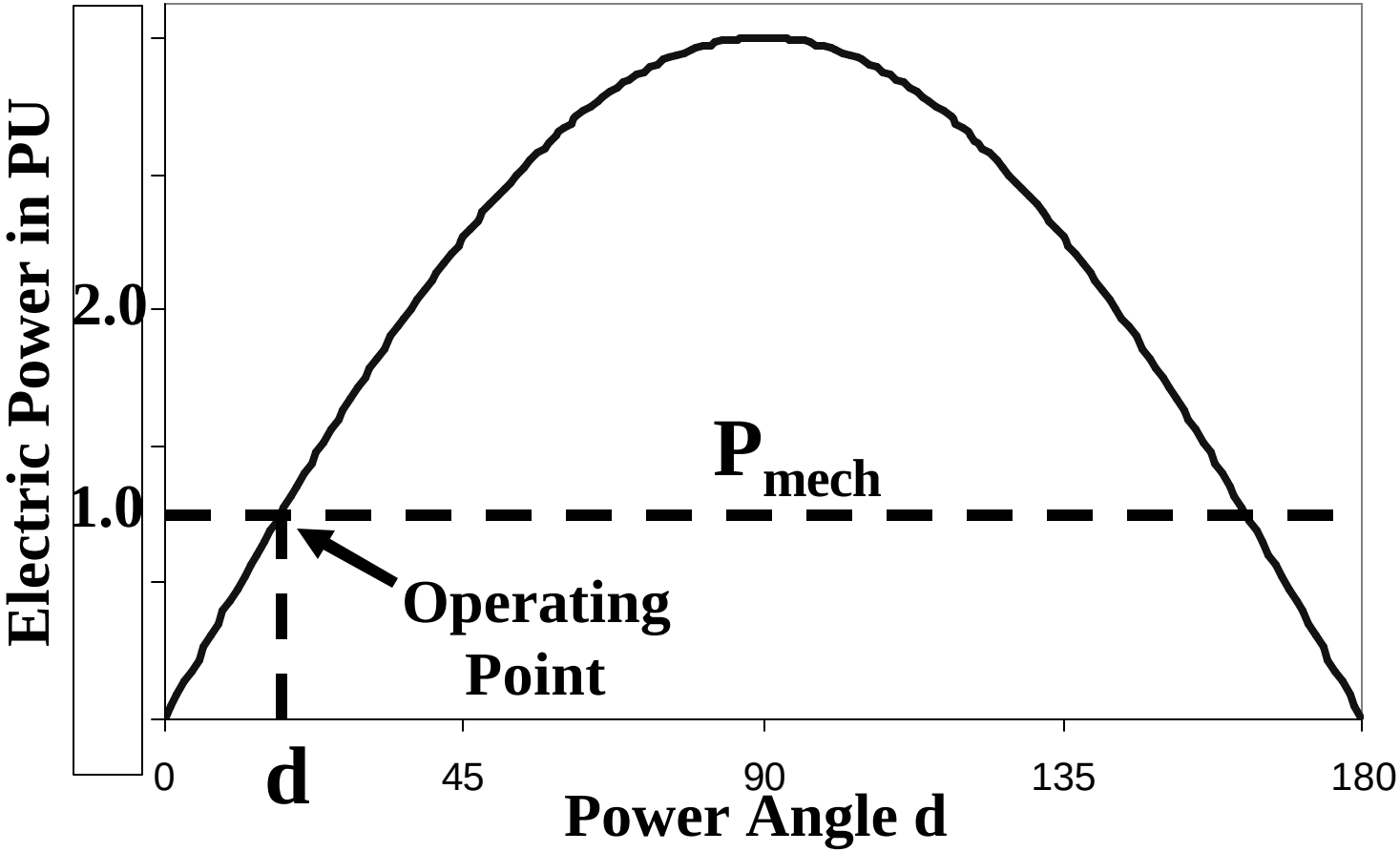
Physics of Power Flow

$$P_{elec} = T_{elec} * ?$$

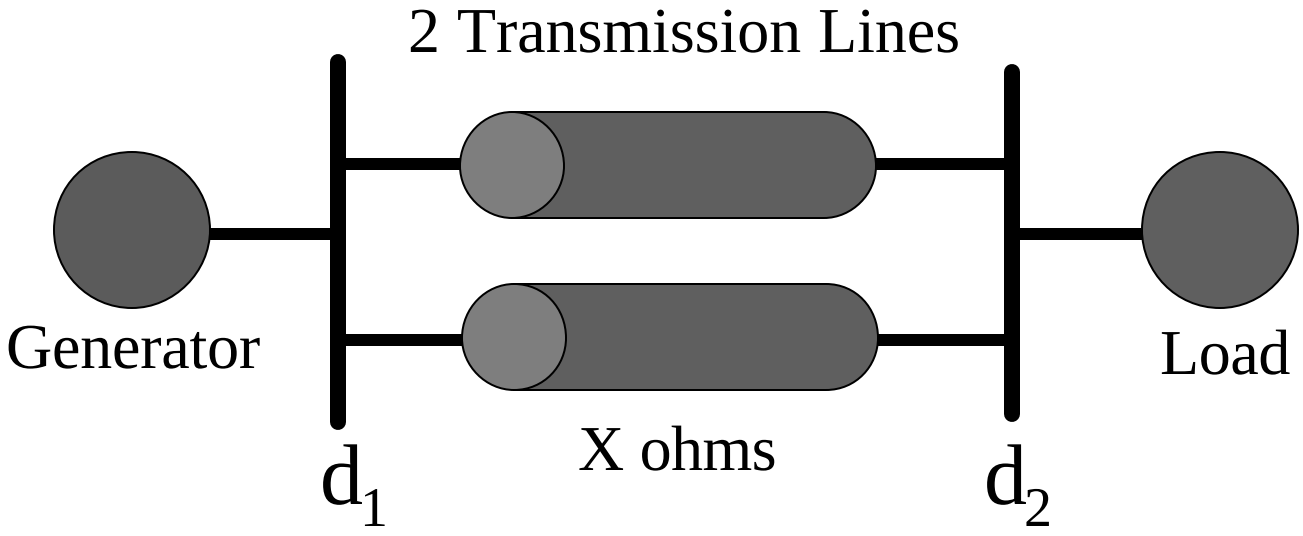


$$P_{elec} = \frac{V^2 * \sin(d_1 - d_2)}{X}$$

Power-Angle Curve

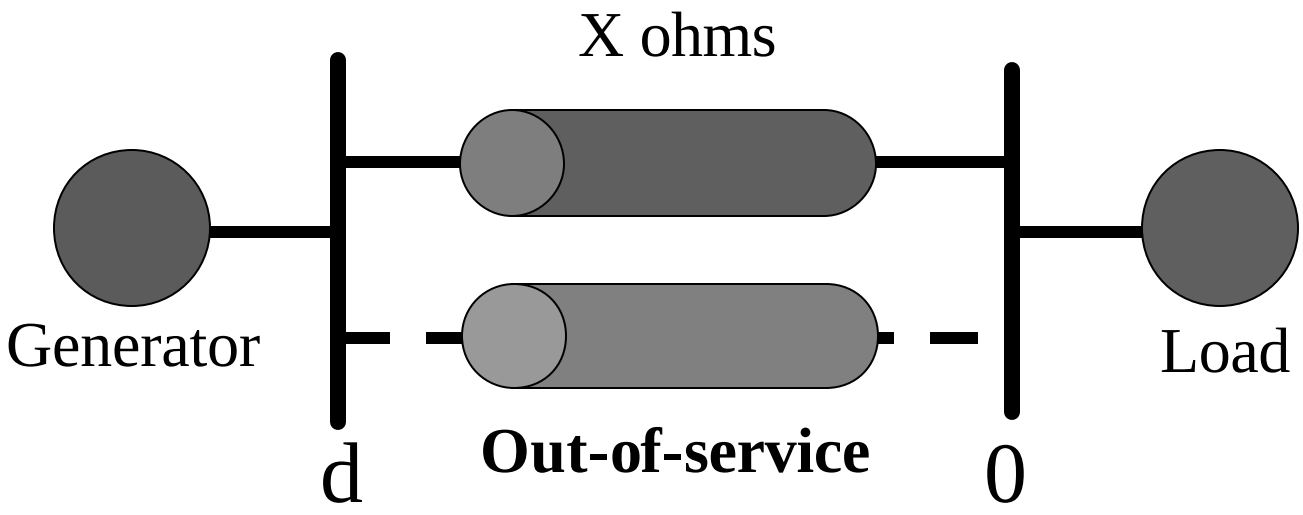


Effect of System Impedance



$$P_{elec} = \frac{V^2 * \sin(d_1 - d_2)}{X/2}$$

Line Taken Out-of-Service

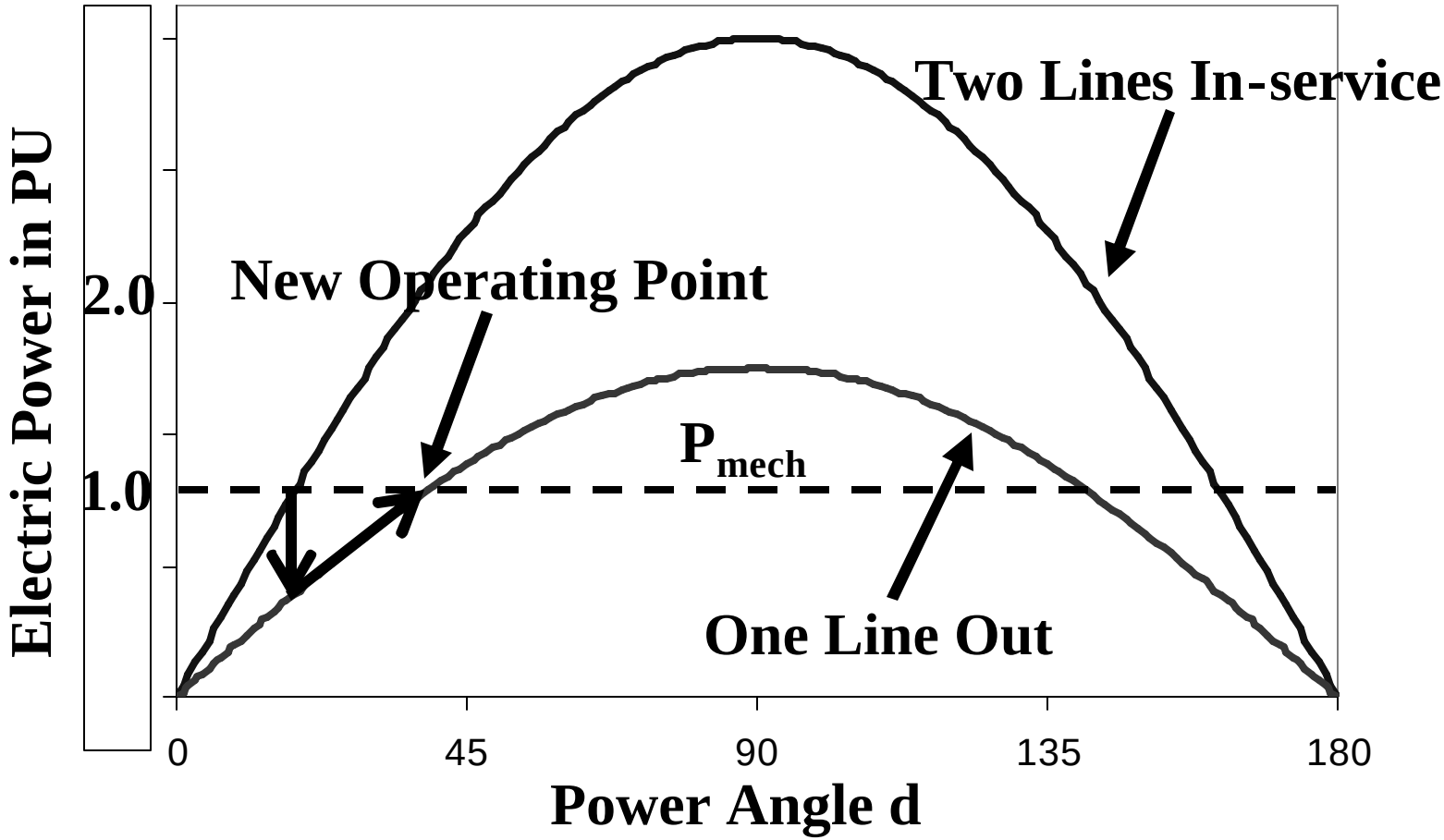


$$P_{2TL} = \frac{V^2 * \sin(d)}{X/2} \qquad P_{1TL} = \frac{V^2 * \sin(d)}{X}$$

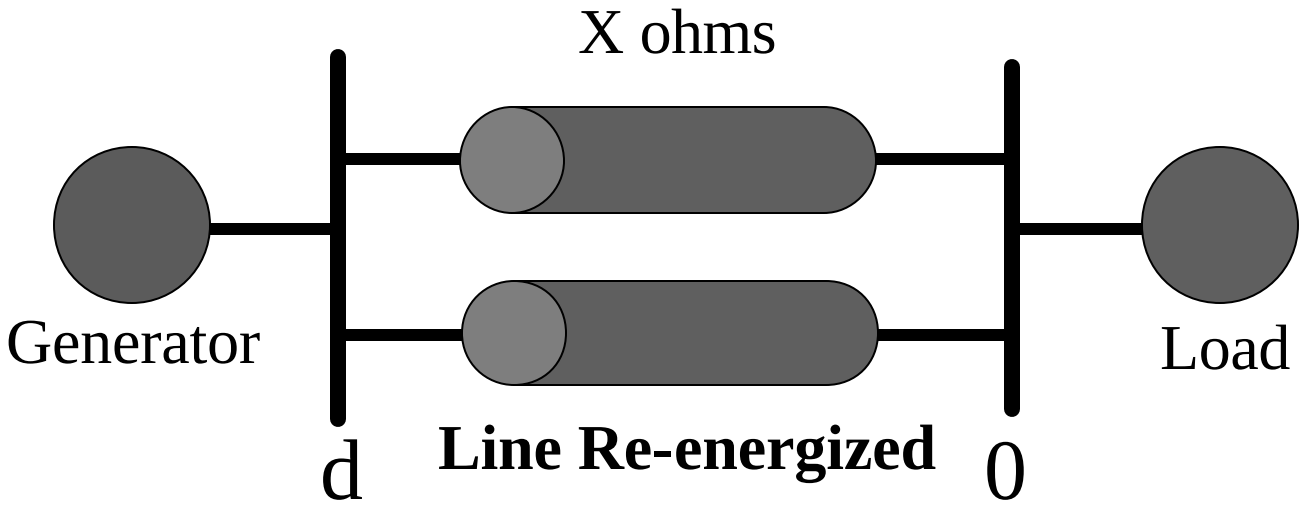
Half the power is transferred while the power angle d remains constant

Line Taken Out-of-Service

P_{elec} experiences a step decrease.
Machine accelerates to the new operating point d.



Line Re-energized

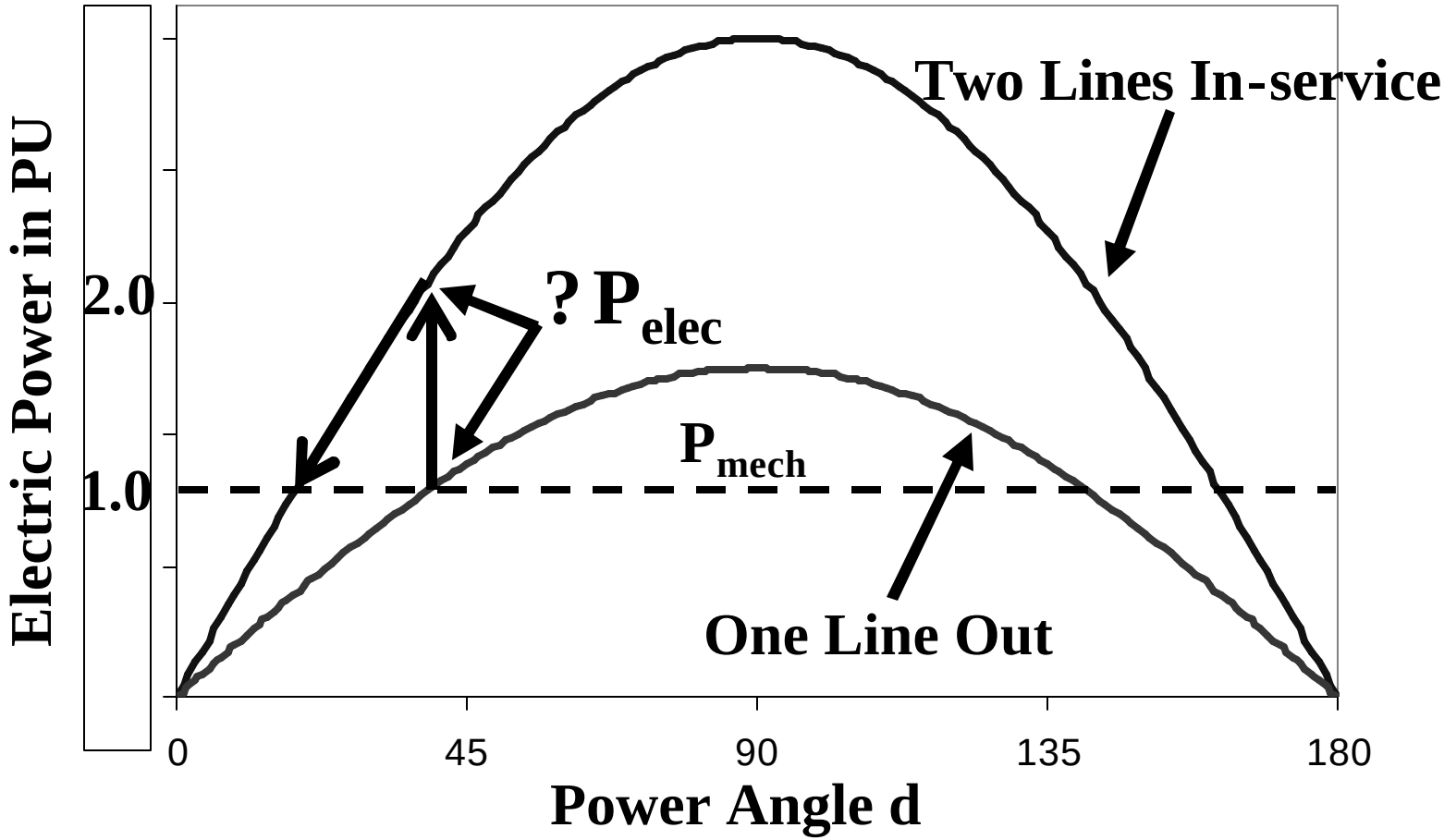


$$P_{2TL} = \frac{V^2 * \sin(d)}{X/2} \qquad P_{1TL} = \frac{V^2 * \sin(d)}{X}$$

However, the angle d is much higher than when the line was removed from service. This creates a larger difference in P_{elec}.

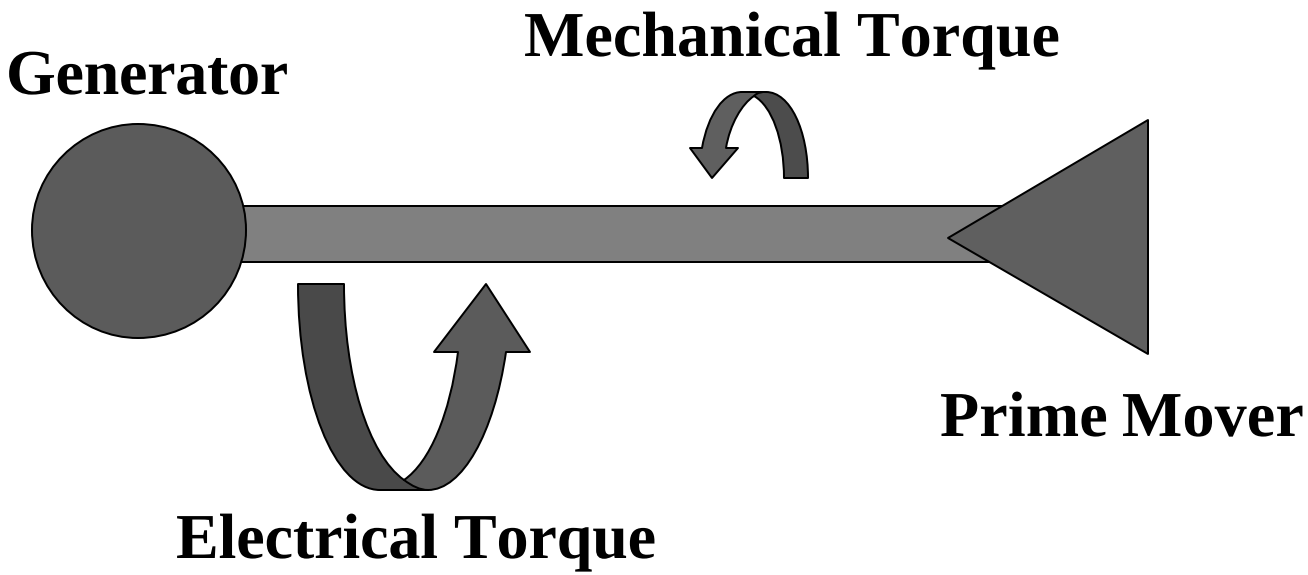
Line Re-energized

P_{elec} experiences a large step increase.
Machine decelerates to the original operating point d.



Line Re-energized

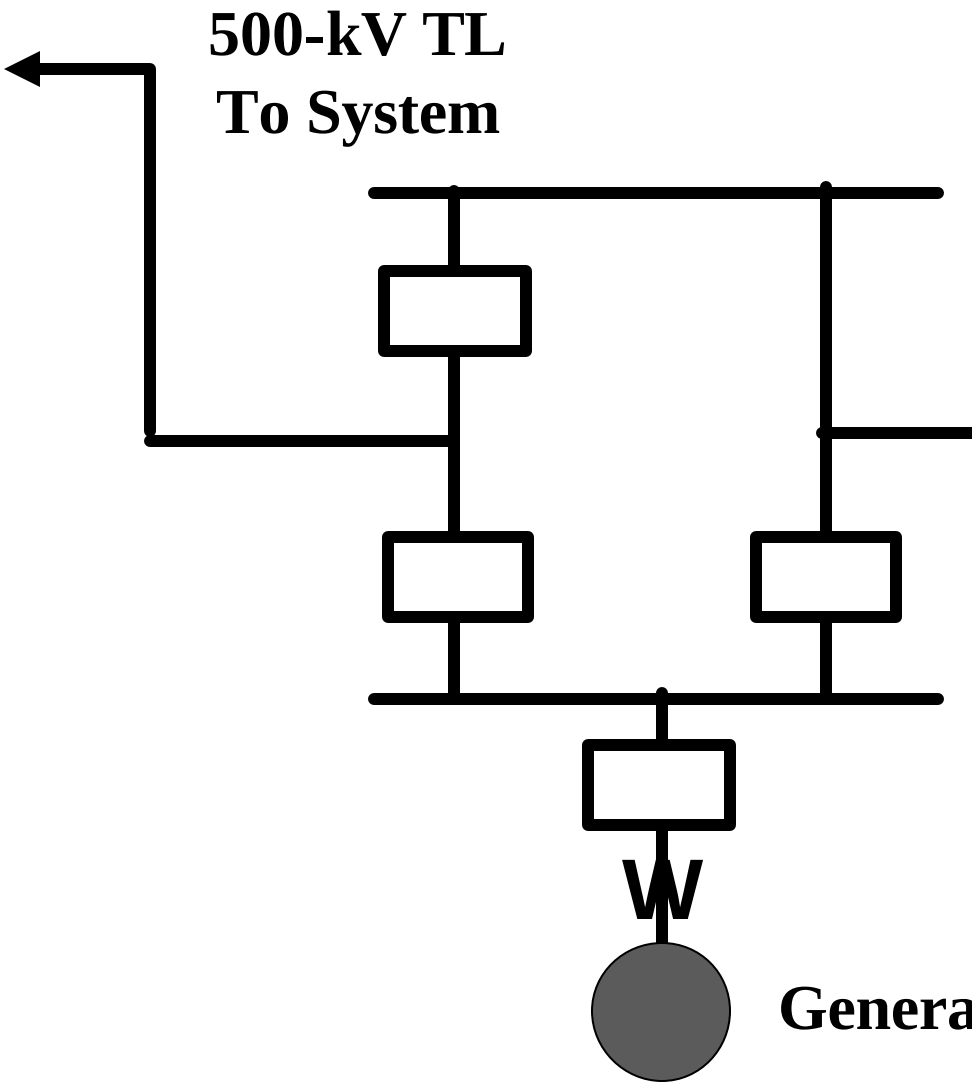
$$J*a = T_{mech} - T_{elec}$$



Because $T_{elec} > T_{mech}$, a decelerating force is instantly applied to the rotor.

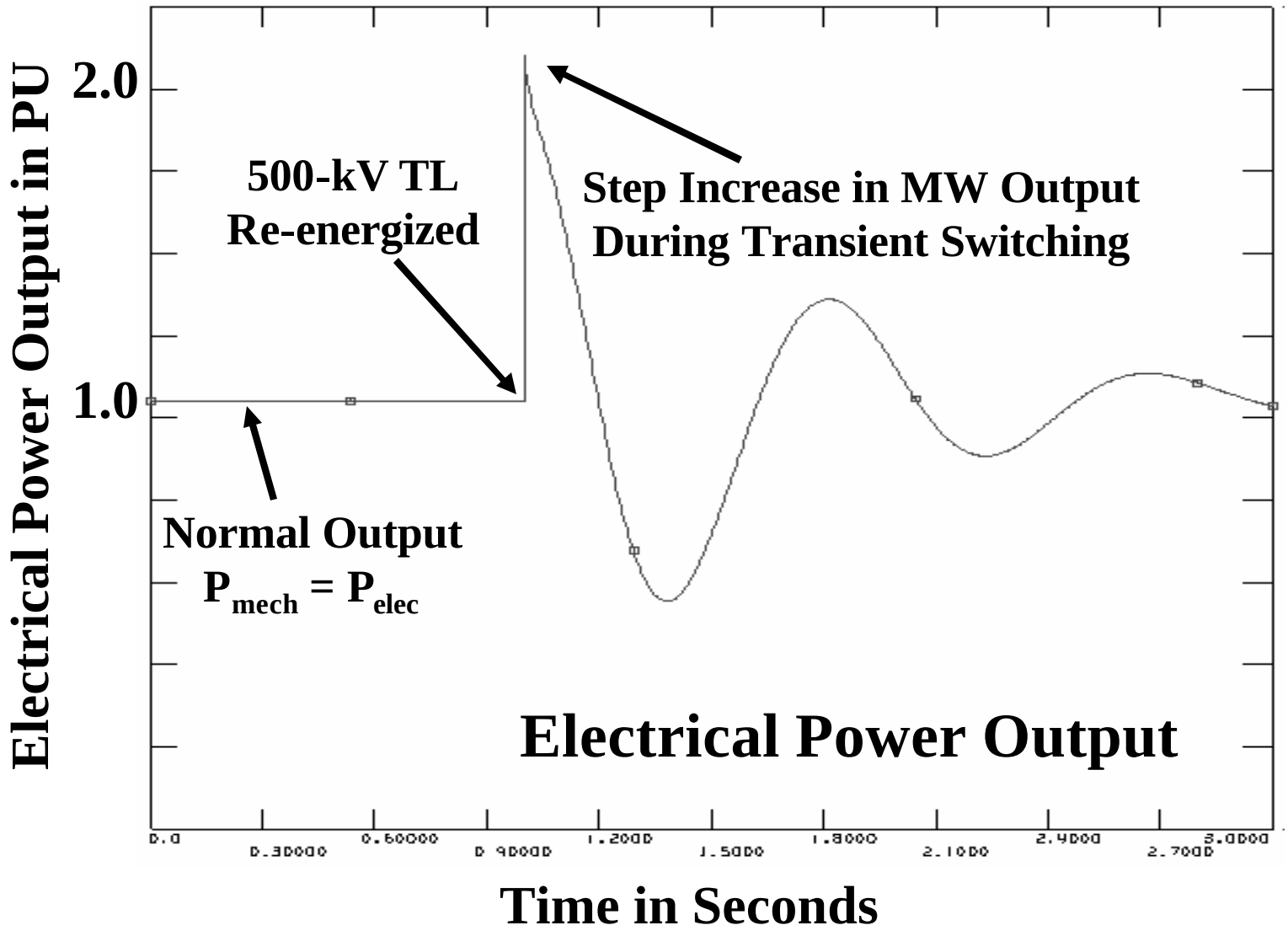
<u>This force can cause rotor deterioration.</u>

Typical IPP Interconnection



One line out-of-service significantly changes the system that the generator sees.

Effect of Switching



Maximum Allowable ?P

- "*IEEE Screening Guide for Planned Steady-State Switching Operations to Minimize Harmful Effects on Steam-Turbine Generators*" (IEEE Trans. On Power Apparatus and Systems, July/August 1980)
- This paper recommends that generators be limited to a ***50% step increase*** in power output during switching events to prevent shaft fatigue or damage.
- It also recommends that the generator manufacturer be contacted to determine if there is the potential for significant deterioration if the 50% step increase is exceeded.

TVA 500-kV Operating Practice

- It is good utility practice to re-energize transmission lines as quickly as possible to maintain system reliability.
- Leaving transmission lines out-of-service longer than planned can lead to system problems.

Options for Generator Owners

1. **Contact the vendor to determine the safe level for the step increase.**
2. Generate at full output and assume the risk of damage.
3. Operate at a lower output level to remain below the safe threshold while lines are out of service.
4. Request TVA to identify a transmission solution. This will likely involve a new transmission line.

Questions?